



(19) Europäisches Patentamt

European Patent Office

Office européen des brevets



(11) EP 0 800 708 B1

(12)

EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention
of the grant of the patent:

16.02.2000 Bulletin 2000/07

(51) Int Cl.7: H01M 8/04

(21) Application number: 95941557.1

(86) International application number:
PCT/CA95/00720

(22) Date of filing: 22.12.1995

(87) International publication number:
WO 96/20508 (04.07.1996 Gazette 1996/30)

(54) ELECTROCHEMICAL FUEL CELL SYSTEM WITH A REGULATED VACUUM EJECTOR FOR RECIRCULATION OF THE FLUID FUEL STREAM

BRENNSTOFFZELLENSYSTEM MIT EINEM REGULIERTEN VAKUUMEJEKTOR FÜR
FLIESSFÄHIGER BRENNSTOFFRÜCKFUHRUNG

SYSTEME DE PILES A COMBUSTIBLE ELECTROCHIMIQUES COMPORTANT UN EJECTEUR A
VIDE REGULE POUR LE RECYCLAGE DU COURANT DE COMBUSTIBLE FLUIDE

(84) Designated Contracting States:
CH DE FR GB IT LI SE

(56) References cited:
FR-A- 2 712 099 US-A- 3 368 923
US-A- 3 716 415 US-A- 3 748 180

(30) Priority: 23.12.1994 US 363706

- PATENT ABSTRACTS OF JAPAN vol. 94, no. 011 & JP,A,06 325780 (MITSUBISHI HEAVY IND LTD), 25 November 1994,
- PATENT ABSTRACTS OF JAPAN vol. 018, no. 658 (E-1643), 13 December 1994 & JP,A,06 260198 (MITSUBISHI HEAVY IND LTD), 16 September 1994,
- PATENT ABSTRACTS OF JAPAN vol. 010, no. 032 (E-379), 7 February 1986 & JP,A,60 189176 (TOSHIBA KK), 26 September 1985,
- PATENT ABSTRACTS OF JAPAN vol. 009, no. 165 (E-327), 10 July 1985 & JP,A,60 039772 (TOSHIBA KK), 1 March 1985,
- PATENT ABSTRACTS OF JAPAN vol. 008, no. 229 (E-273), 20 October 1984 & JP,A,59 111272 (TOSHIBA KK), 27 June 1984,
- PATENT ABSTRACTS OF JAPAN vol. 007, no. 107 (E-174), 11 May 1983 & JP,A,58 030075 (FUJI DENKI SEIZO KK; OTHERS: 01), 22 February 1983,
- PATENT ABSTRACTS OF JAPAN vol. 005, no. 192 (E-085), 8 December 1981 & JP,A,56 114287 (CENTRAL RES INST OF ELECTRIC POWER IND; OTHERS: 01), 8 September 1981,
- PATENT ABSTRACTS OF JAPAN vol. 010, no. 213 (E-422), 25 July 1986 & JP,A,61 051771 (MITSUBISHI ELECTRIC CORP), 14 March 1986,

(43) Date of publication of application:
15.10.1997 Bulletin 1997/42

(73) Proprietors:

- BALLARD POWER SYSTEMS INC.
Burnaby, British Columbia V5J 5J9 (CA)
- DBB Fuel Cell Engines GmbH
73230 Kirchheim/Teck-Nabern (DE)

(72) Inventors:

- MERRITT, Robert, D.
Vancouver, British Columbia V6R 3A3 (CA)
- GORBELL, Brian, N.
North Vancouver, British Columbia V7H 1K (CA)

(74) Representative: Haecker, Walter, Dipl.-Phys. et al
Hoeger, Stellrecht & Partner
Uhlandstrasse 14 c
70182 Stuttgart (DE)

EP 0 800 708 B1

Note: Within nine months from the publication of the mention of the grant of the European patent, any person may give notice to the European Patent Office of opposition to the European patent granted. Notice of opposition shall be filed in a written reasoned statement. It shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

Description

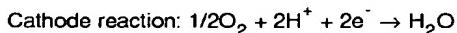
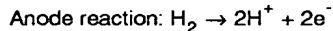
[0001] The present invention relates to electrochemical fuel cells. More particularly, the present invention relates to an electric power generation system which includes a fuel cell stack and a regulated vacuum ejector for recirculating the fluid fuel stream. The system maintains a uniform fuel recirculation ratio and a balance between the pressure of the fuel stream and the pressure of oxidant stream.

Background Of The Invention

[0002] Electrochemical fuel cells convert fuel and oxidant to electricity and reaction product. Solid polymer electrochemical fuel cells generally employ a membrane electrode assembly ("MEA") which comprises an ion exchange membrane or solid polymer electrolyte disposed between two electrodes formed of porous, electrically conductive sheet material, typically carbon fiber paper. The MEA contains a layer of catalyst, typically in the form of finely comminuted platinum, at each membrane/electrode interface to induce the desired electrochemical reaction. The electrodes are electrically coupled to provide a path for conducting electrons between the electrodes to an external load.

[0003] At the anode, the fuel permeates the porous electrode material and reacts at the catalyst layer to form cations, which migrate through the membrane to the cathode. At the cathode, the oxygen-containing gas supply reacts at the catalyst layer to form anions. The anions formed at the cathode react with the cations to form a reaction product.

[0004] In electrochemical fuel cells employing hydrogen as the fuel and oxygen-containing air (or substantially pure oxygen) as the oxidant, the catalyzed reaction at the anode produces hydrogen cations (protons) from the fuel supply. The ion exchange membrane facilitates the migration of hydrogen ions from the anode to the cathode. In addition to conducting hydrogen ions, the membrane isolates the hydrogen-containing fuel stream from the oxygen-containing oxidant stream. At the cathode, oxygen reacts at the catalyst layer to form anions. The anions formed at the cathode react with the hydrogen ions that have crossed the membrane to form liquid water as the reaction product. The anode and cathode reactions in hydrogen/oxygen fuel cells are shown in the following equations:



[0005] In typical fuel cells, the MEA is disposed between two electrically conductive plates, each of which has at least one flow passage engraved or milled there-

in. These fluid flow field plates are typically formed of graphite. The flow passages direct the fuel and oxidant to the respective electrodes, namely, the anode on the fuel side and the cathode on the oxidant side. In a single cell arrangement, fluid flow field plates are provided on each of the anode and cathode sides. The fluid flow field plates act as current collectors, provide support for the electrodes, provide access channels for the fuel and oxidant to the respective anode and cathode surfaces, and provide channels for the removal of water formed during operation of the cell.

[0006] Two or more fuel cells can be connected together, generally in series but sometimes in parallel, to increase the overall power output of the assembly. In series arrangements, one side of a given fluid flow field plate serves as an anode plate for one cell and the other side of the fluid flow field plate can serve as the cathode plate for the adjacent cell. Such a series connected multiple fuel cell arrangement is referred to as a fuel cell stack, and is usually held together in its assembled state by tie rods and end plates. The stack typically includes manifolds and inlet ports for directing the fluid fuel stream (substantially pure hydrogen, methanol reformat or natural gas reformat) and the fluid oxidant stream (substantially pure oxygen or oxygen-containing air) to the anode and cathode flow field channels. The stack also usually includes a manifold and inlet port for directing the coolant fluid stream, typically water, to interior channels within the stack to absorb heat generated by the exothermic reaction of hydrogen and oxygen within the fuel cells. The stack also generally includes exhaust manifolds and outlet ports for expelling the unreacted fuel and oxidant gases, each carrying entrained water, as well as an exhaust manifold and outlet port for the coolant water exiting the stack.

[0007] Solid polymer fuel cells generally employ perfluorosulfonic ion exchange membranes, such as those sold by DuPont under its NAFION trade designation and by Dow under the trade designation XUS 13204.10. **[0008]** When employing such membranes, the fuel and oxidant reactant streams are each generally humidified before they are introduced to solid polymer fuel cells so as to facilitate cation exchange and to avoid drying, and thus damaging, the ion exchange membranes separating the anode and cathode of each cell.

[0009] Each of the fuel cells making up the stack is typically flooded with the selected fuel and oxidant at a desired pressure. The pressure is generally controlled by a regulator at the source of the reactant. When an electrical load is placed on the circuit connecting the electrodes, the fuel and oxidant are consumed in direct proportion to the electrical current drawn by the load.

[0010] Each reactant stream exiting the fuel cell stack generally contains water. The outlet fuel stream from the anodes generally contains the water added to humidify the stream plus any product water drawn across the membrane from the cathode and absorbed as vapor in the fuel stream. The outlet oxidant stream from the cath-

odes generally contains the water added to humidify the stream plus product water formed at the cathode that is either entrained as water droplets or is absorbed as vapor in the oxidant stream. As the power output of the fuel cell stack is increased, more water accumulates at the anode and at the cathode, thereby increasing the recirculation flow rate required to remove water and keep the flow channels in the stack unobstructed.

[0010] Excess water extracted from one or both of the reactant streams exiting the fuel cell can be accumulated in a separator or knockout drum. The excess water so accumulated can then be recirculated and used as a source of coolant fluid or humidification water, or simply drained from the system.

[0011] When one of the reactants fed to the fuel cells is substantially pure hydrogen or oxygen, the unconsumed reactant exhausted from the fuel cells may be recirculated to minimize waste that would result from venting the reactant to the atmosphere. Excess water may be removed from the recirculated reactant stream before it is merged with the corresponding incoming fresh reactant stream upstream of the inlet to the fuel cell stack. Alternatively, the recirculated reactant stream containing water vapor may be merged directly with the incoming fresh reactant stream, thereby humidifying the incoming fresh reactant stream and avoiding the need for a separate humidifier.

[0012] Similarly, when one or both of the reactants is a dilute reactant, such as a reformate or air, the unconsumed reactant exhausted from the fuel cells may also be recirculated, particularly in the case of the fuel stream. However, the dilute reactant stream is more often discarded after it has passed once through the fuel cell stack, particularly when the dilute reactant is air. The excess water in the outlet dilute reactant stream is generally removed in a separator or knockout drum. The exhaust reactant stream is then generally vented to the atmosphere.

[0013] It is often advantageous to integrate the product water separated from the outlet reactant streams with the coolant stream, and thereby use the product water generated electrochemically in the fuel cell stack to regulate the temperature of the stack. In this regard, the use of product water as the coolant avoids the need to provide a separate external source of coolant fluid, since the water generated by the fuel cells is itself a suitable coolant fluid.

[0014] In characterizing systems employing recirculated reactant streams, it is convenient to define the term "recirculation ratio". As used herein, "recirculation ratio" is the amount of a reactant supplied to the fuel cell stack divided by the amount of the reactant consumed in one pass through the fuel cell stack. In typical hydrogen/oxygen fuel cell stacks, the hydrogen recirculation ratio ranges from 1.2 to 5.0, and more preferably from 1.5 to 2.0.

[0015] In fuel cell based electric power generation systems in which one or more of the reactant streams

is recirculated, vacuum ejectors have been employed to effect recirculation. Winters U.S. Patent No. 3,462,308 discloses a fuel cell system in which each of the fuel and oxidant streams discharged from the fuel cell is recirculated and merged with the respective incoming, fresh fuel and oxidant streams by means of ejectors 23 and 23'. Each ejector is described as including a venturi throat. However, Winter's ejector configuration is designed for fixed-point operation in that a constant reactant stream pressure drop is required across each of the ejectors. In order to maintain the necessary pressure drop across the ejectors to effect recirculation, Winter's system discharges the recirculated reactant streams as required via vent valves 21 and 21'. Thus, Winter's reactant recirculation system has a load-following capability, but incurs a serious efficiency penalty due to the venting of the recirculated reactant streams to the atmosphere.

[0016] Vacuum ejectors have also been incorporated 20 into the fuel processing subsystem of a reformate-based fuel cell electric power generation system. In Fanciullo et al. U.S. Patent No. 3,745,047, an ejector is employed to draw steam into a fuel stream prior to its introduction into a reformer. In the Fanciullo system, however, an 25 ejector is not employed to recirculate the fuel stream (or the oxidant stream), since the outlet fuel stream is not recirculated to the fuel cell but is instead directed through conduit 34 to the reformer burner.

[0017] The primary purpose of an ejector is to transport 30 a gas, liquid, powder or solid particles from one pressure level to a relatively higher pressure level. Ejectors generally contain no moving parts and are therefore considered to be passive devices. In an ejector, pressurized motive fluid passes through a nozzle, where its 35 pressure is dissipated in accelerating the fluid to a high velocity as it exits the mouth of the nozzle. The high velocity fluid stream exiting the nozzle entrains relatively low pressure fluid introduced at a suction inlet to the ejector. Entrainment of the low pressure suction fluid 40 with the motive fluid causes the suction fluid to move with the motive fluid. The two streams mix as they pass into a diffuser portion of the ejector. The velocity profile of the stream changes along the fluid path of the ejector, and the pressure of the stream rises as the fluid reaches 45 the ejector outlet. As the motive fluid flow rate increases, the motive pressure must also be increased to maintain constant discharge pressure due to the increased pressure drop across the ejector nozzle. As the motive/discharge pressure increases, the suction fluid flow rate also increases.

[0018] Therefore, the present invention proposes an 50 electric power generation system comprising:

(a) a fuel cell stack comprising a first reactant stream inlet, a first reactant stream outlet, a second reactant stream inlet, and at least one fuel cell for promoting an electrocatalytic reaction of a first reactant stream introduced at said first reactant

stream inlet with a second reactant stream introduced at said second reactant stream inlet to produce electricity, reaction product, and heat;

(b) a pressurized first reactant supply having a pressure control valve for regulating the pressure of said first reactant supply;

(c) a vacuum ejector interposed between said first reactant supply and said first reactant stream inlet, said ejector comprising a motive inlet, a suction inlet, and a discharge outlet, said motive inlet fluidly connected to said first reactant supply, said suction inlet fluidly connected to said first reactant stream outlet, and said discharge outlet fluidly connected to said first reactant stream inlet;

(d) a first pressure transducer interposed in said first reactant stream between said discharge outlet and said suction inlet, said first pressure transducer detecting the pressure of said first reactant stream and transmitting a corresponding signal to said pressure control valve;

(e) a pressurized second reactant supply fluidly connected to said second reactant stream inlet; and

(f) a second pressure transducer interposed between said second reactant supply and said second reactant stream inlet, said second pressure transducer capable of detecting the pressure of said second reactant stream and transmitting a corresponding signal to said pressure control valve;

whereby said first pressure transducer transmits a signal to said pressure control valve to increase the pressure of said first reactant supply when the detected pressure of said first reactant stream falls below a predetermined value and said first pressure transducer transmits a signal to said pressure control valve to decrease the pressure of said first reactant supply when the detected pressure of said first reactant stream exceeds a predetermined value and whereby said second pressure transducer transmits a signal to said pressure control valve to increase the pressure of said first reactant supply when the detected pressure of said second reactant stream increases and said second pressure transducer transmits a signal to said pressure control valve to decrease the pressure of said first reactant supply when the detected pressure of said second reactant stream decreases.

[0019] In preferred embodiments of the electric power generation system, the first reactant is a fuel and the second reactant is an oxidant. In operation of said preferred embodiment, the pressure transducer transmits a signal to the pressure control valve to increase the pressure of the fuel supply when the detected pressure of the fuel stream falls below a predetermined value, as

would occur when the load, and consequently the fuel stream flow rate through the ejector, increases. Conversely, the pressure transducer transmits a signal to the pressure control valve to decrease the pressure of the fuel supply when the detected pressure of the fuel stream exceeds a predetermined value, as would occur when the load, and consequently the fuel stream flow rate through the ejector, decreases.

[0020] In the most preferred system, the fuel cell stack further comprises a second reactant stream outlet.

[0021] Preferably, the first pressure transducer is interposed in said first reactant stream between said discharge outlet and said first reactant stream inlet.

[0022] The signal transmitted by the first pressure transducer can be an electrical or mechanical signal, preferably an electronic, hydraulic, or pneumatic signal, which corresponds to the detected pressure of the first reactant stream and is transmitted to the pressure control valve.

[0023] In preferred systems, the pressurized first reactant supply comprises substantially pure hydrogen. When the second reactant stream is an oxidant stream, the pressurized second reactant supply preferably comprises oxygen, and the most preferred oxidant supply is oxygen-containing air. In most preferred systems where the first reactant supply comprises substantially pure hydrogen and the second reactant supply comprises oxygen, said reaction product is water.

[0024] In preferred systems, the at least one fuel cell comprises an ion exchange membrane and the system further comprises a first reactant stream humidifier for imparting water vapor to the first reactant stream and a second reactant stream humidifier for imparting water vapor to the second reactant stream.

[0025] Preferably, a water separator is interposed between the first reactant stream outlet and the suction inlet whereby at least a portion of the water contained in the first reactant stream is removed.

[0026] The pressure transducer is preferably interposed in the oxidant stream between the discharge outlet and the oxidant stream inlet.

[0027] In most preferred systems, the fuel stream pressure transducer transmits a signal to the pressure control valve to increase the pressure of the oxidant supply when the detected pressure of the fuel stream increases, and transmits a signal to the pressure control valve to decrease the pressure of the oxidant supply when the detected pressure of the fuel stream decreases.

[0028] The present invention further proposes a method for recirculating a first reactant stream in an electric power generation system comprising a fuel cell stack comprising a first reactant stream inlet, a first reactant stream outlet, a second reactant stream inlet, and at least one fuel cell for promoting the electrocatalytic reaction of the first reactant stream introduced at the first reactant stream inlet with a second reactant stream introduced at the second reactant stream inlet to produce

electricity, reaction product, and heat, the system further comprising a pressurized first reactant supply having a pressure control valve for regulating the pressure of the first reactant supply, and a pressurized second reactant supply, the method comprising the steps of:

- (a) interposing a vacuum ejector between the first reactant supply and the first reactant stream inlet, said ejector comprising a motive inlet, a suction inlet, and a discharge outlet;
- (b) fluidly connecting said motive inlet to said first reactant supply;
- (c) fluidly connecting said suction inlet to said first reactant stream outlet;
- (d) fluidly connecting said discharge outlet to said first reactant stream inlet;
- (e) interposing a first pressure transducer between said discharge outlet and said suction inlet, said first pressure transducer capable of detecting the pressure of said first reactant stream and transmitting a corresponding signal to said pressure control valve;
- (f) transmitting a signal to said pressure control valve to increase the pressure of said first reactant supply when the detected pressure of said first reactant stream falls below a predetermined value;
- (g) transmitting a signal to said pressure control valve to decrease the pressure of said first reactant supply when the detected pressure of said first reactant stream exceeds a predetermined value;
- (h) interposing a second pressure transducer between said second reactant supply and said second reactant stream inlet, said second pressure transducer capable of detecting the pressure of said second reactant stream and transmitting a corresponding signal to said pressure control valve;
- (i) transmitting a signal to said pressure control valve to increase the pressure of said first reactant supply when the detected pressure of said second reactant stream increases; and
- (j) transmitting a signal to said pressure control valve to decrease the pressure of said first reactant supply when the detected pressure of said second reactant stream decreases.

[0029] In preferred embodiments of this method, the first reactant stream comprises hydrogen and the second reactant stream comprises oxygen.

Brief Description Of The Drawings

[0030]

- 5 Fig. 1 is a schematic diagram of one embodiment of a fuel cell based electric power generation system with a regulated vacuum ejector for recirculation of the fluid fuel stream
 - 10 Fig. 2 is a side sectional view of the vacuum ejector illustrated schematically in Fig. 1
- #### Detailed Description Of The Preferred Embodiments
- 15 **[0031]** Turning first to Fig. 1, a fuel cell based electric power generation system 10 includes a fuel cell stack 100, preferably comprising a plurality of fuel cells. The fuel cell stack 100 is more completely described in Watkins et al. U.S. Patent No. 5,200,278 (in FIGS. 1-6 and the accompanying text), which is incorporated herein by reference in its entirety. A preferred reactant supply and control system for fuel cells of the type which make up stack 100 is described in Merritt et al. U.S. Patent No. 5,366,821, which is also incorporated herein by reference in its entirety.
 - 20 **[0032]** Each of the fuel cells of stack 100 has an anode, a cathode, an electrolyte (preferably a solid polymer ion exchange membrane), and cooling/humidification units, as will be explained in more detail below. As illustrated schematically in FIG. 1, fuel cell stack 100 includes a fuel stream inlet 110, a fuel stream outlet 112, an oxidant stream inlet 114, an oxidant stream outlet 116, a coolant/humidification fluid inlet 118, and a coolant/humidification fluid outlet 119.
 - 25 **[0033]** Fuel cell stack 100 includes negative and positive bus plates 102, 104, respectively, to which a circuit comprising a variable load 106 and a contactor switch 108 are electrically connected. In addition to stack 100, system 10 also includes a fuel circuit, an oxidant circuit, and a cooling/humidification circuit.
 - 30 **[0034]** The fuel circuit of system 10 in FIG. 1 includes a pressurized substantially pure hydrogen supply 120 having fuel feed line 136. Pressure control valve 122 capable of receiving and responding to signals, as shown and as explained in more detail below, regulates the pressure of the fuel stream from feed line 136. A vacuum ejector 124 is interposed between fuel supply 120 and fuel stream inlet 110 of stack 100.
 - 35 **[0035]** Ejector 124 includes a motive inlet 126, a suction inlet 128, and a discharge outlet 130. Motive inlet 126 is fluidly connected to the outlet of pressure control valve 122 and receives pressurized fuel stream 136, as shown. Suction inlet 128 is fluidly connected to the fuel stream outlet 112 of stack 100, so as to recirculate the outlet fuel stream 142. A water separator or knockout drum 144 is interposed between the fuel stream outlet 112 of stack 100 and the suction inlet 128 of ejector 124. Water separator 144 removes at least a portion of the

water contained in outlet fuel stream 142 before directing the stream 146 to the suction inlet 128 of ejector 124. Inlet fuel stream 140 is thus formed by the merger of recirculated fuel stream 146 and fresh pressurized fuel stream 138.

[0036] Discharge outlet 130 of ejector 124 is fluidly connected to the fuel stream inlet 110 of stack 100. A pressure transducer 132 is interposed between discharge outlet 130 and fuel stream inlet 110. Pressure transducer 132 detects the pressure of inlet fuel stream 140 and is capable of transmitting a signal corresponding to the detected pressure in inlet fuel stream 140. The signal from pressure transducer 132 to pressure control valve 122, shown by a broken line in FIG. 1, can be electronic or mechanical. In this regard, an electrical, hydraulic or pneumatic signal, which corresponds to the detected pressure of the inlet fuel stream, is transmitted from pressure transducer 132 to the pressure control valve 122. In operation, pressure transducer 132 transmits a signal to pressure control valve 122 so as to increase the pressure of fuel stream 138 when the detected pressure of inlet fuel stream 140 falls below a predetermined value, typically a value between 20-50 psi gauge, nominally 30 psi gauge. The detected pressure of inlet fuel stream 140 would fall below that predetermined value when the load, and consequently the fuel stream flow rate through the ejector, increases. Conversely, pressure transducer 132 transmits a signal to pressure control valve 122 so as to decrease the pressure of fuel stream 138 when the detected pressure of inlet fuel stream 140 exceeds a predetermined value. The detected pressure of inlet fuel stream 140 would exceed that predetermined value when the load, and consequently the fuel stream flow rate through the ejector, decreases. The interaction of pressure transducer 132 and pressure control valve 122 causes ejector 124 to be load-following and therefore capable of maintaining a relatively uniform inlet fuel stream pressure to the fuel cell stack over a range of potential operating conditions, as well as maintaining a relatively uniform outlet fuel stream recirculation ratio.

[0037] The oxidant circuit of system 10 in FIG. 1 includes a pressurized oxygen-containing air supply 150 as the source for inlet oxidant stream 152. Pressure transducer 156 is interposed between oxidant supply 150 and oxidant stream inlet 114. Pressure transducer 156 detects the pressure of inlet oxidant stream 152 and is capable of transmitting a signal corresponding to the detected pressure in inlet oxidant stream 152. The signal from pressure transducer 156 to pressure control valve 122, shown by a broken line in FIG. 1, can be electronic or mechanical. In this regard, an electrical, hydraulic or pneumatic signal, which corresponds to the detected pressure of the inlet fuel stream, is transmitted from pressure transducer 156 to the pressure control valve 122. In operation, pressure transducer 156 transmits a signal to pressure control valve 122 so as to increase the pressure of fuel stream 138 when the detect-

ed pressure of inlet oxidant stream 152 increases. Conversely, pressure transducer 156 transmits a signal to pressure control valve 122 to decrease the pressure of fuel stream 138 when the detected pressure of inlet oxidant stream 152 decreases. Thus, pressure transducer 156 acts as a bias on pressure control valve 122 to maintain a balance between the pressure of inlet fuel stream 140 and the pressure of inlet oxidant stream 152.

[0038] Outlet oxidant stream 154 is discharged from stack 100 via oxidant stream outlet 116. A water separator or knockout drum 158 removes at least a portion of the water contained in outlet oxidant stream 154. As shown in FIG. 1, outlet oxidant stream 158 from water separator 158 is expelled from system 10 to the atmosphere.

[0039] The cooling/humidification circuit of system 10 in FIG. 1 includes a reservoir 162. Reservoir 162 can receive from water separators 144, 156 the water removed from the outlet fuel and oxidant streams. The coolant/humidification fluid stream 164 from reservoir 162 is directed by a pump 166 as a pressurized stream 168 to a coolant/humidification fluid inlet 118 of stack 100. The outlet coolant/humidification fluid stream 170 is discharged from the stack 100 via a coolant/humidification fluid outlet 119. The outlet coolant/humidification fluid stream 170 is then returned to reservoir 162, as shown in FIG. 1.

[0040] FIG. 2 is a side sectional view of the vacuum ejector 124 illustrated schematically in FIG. 1. Vacuum ejector 124 includes a motive inlet 126, a suction inlet 128, and a discharge outlet 130. Ejector 124 also includes a motive nozzle 202, a motive chest 204, a diffuser portion 206, an inlet diffuser 208, a diffuser throat 210, and an outlet diffuser 212.

[0041] A vacuum ejector could also be incorporated into a fuel cell based electric power generation system employing substantially pure oxygen as the oxidant stream to recirculate the fluid oxidant stream. In this regard, essentially the same principles set forth above with respect to vacuum ejector recirculation of the fluid fuel stream would apply to vacuum ejector recirculation of the fluid oxidant stream.

[0042] While particular elements, embodiments and applications of the present invention have been shown and described, it will be understood, of course, that the invention is not limited thereto since modifications may be made by those skilled in the art, particularly in light of the foregoing teachings. It is therefore contemplated by the appended claims to cover such modifications as incorporate those features which come within the spirit and scope of the invention.

Claims

- 55 1. An electric power generation system comprising:
 (a) a fuel cell stack comprising a first reactant

stream inlet, a first reactant stream outlet, a second reactant stream inlet, and at least one fuel cell for promoting an electrocatalytic reaction of a first reactant stream introduced at said first reactant stream inlet with a second reactant stream introduced at said second reactant stream inlet to produce electricity, reaction product, and heat;

(b) a pressurized first reactant supply having a pressure control valve for regulating the pressure of said first reactant supply;

(c) a vacuum ejector interposed between said first reactant supply and said first reactant stream inlet, said ejector comprising a motive inlet, a suction inlet, and a discharge outlet, said motive inlet fluidly connected to said first reactant supply, said suction inlet fluidly connected to said first reactant stream outlet, and said discharge outlet fluidly connected to said first reactant stream inlet;

(d) a first pressure transducer interposed in said first reactant stream between said discharge outlet and said suction inlet, said first pressure transducer detecting the pressure of said first reactant stream and transmitting a corresponding signal to said pressure control valve;

(e) a pressurized second reactant supply fluidly connected to said second reactant stream inlet; and

(f) a second pressure transducer interposed between said second reactant supply and said second reactant stream inlet, said second pressure transducer capable of detecting the pressure of said second reactant stream and transmitting a corresponding signal to said pressure control valve;

whereby said first pressure transducer transmits a signal to said pressure control valve to increase the pressure of said first reactant supply when the detected pressure of said first reactant stream falls below a predetermined value and said first pressure transducer transmits a signal to said pressure control valve to decrease the pressure of said first reactant supply when the detected pressure of said first reactant stream exceeds a predetermined value and whereby said second pressure transducer transmits a signal to said pressure control valve to increase the pressure of said first reactant supply when the detected pressure of said second reactant stream increases and said second pressure transducer transmits a signal to said pressure control valve to decrease the pressure of said first reactant supply when the detected pressure of said second reactant stream decreases.

2. The electric power generation system of claim 1

wherein said fuel cell stack further comprises a second reactant stream outlet.

- 5 3. The electric power generation system of claim 1 wherein said first pressure transducer is interposed in said first reactant stream between said discharge outlet and said first reactant stream inlet.
- 10 4. The electric power generation system of claim 1 wherein said first pressure transducer transmits an electronic signal to said pressure control valve which corresponds to the detected pressure of said first reactant stream.
- 15 5. The electric power generation system of claim 1 wherein said first pressure transducer transmits a hydraulic signal to said pressure control valve which corresponds to the detected pressure of said first reactant stream.
- 20 6. The electric power generation system of claim 1 wherein said first pressure transducer transmits a pneumatic signal to said pressure control valve which corresponds to the detected pressure of said first reactant stream.
- 25 7. The electric power generation system of claim 1 wherein said first reactant is a fuel and said second reactant is an oxidant.
- 30 8. The electric power generation system of claim 7 wherein said pressurized first reactant supply comprises substantially pure hydrogen.
- 35 9. The electric power generation system of claim 8 wherein said pressurized second reactant supply comprises oxygen and said reaction product is water.
- 40 10. The electric power generation system of claim 9 wherein said second reactant supply is oxygen-containing air.
- 45 11. The electric power generation system of claim 1 wherein said at least one fuel cell comprises an ion exchange membrane and the system further comprises a first reactant stream humidifier for imparting water vapor to said first reactant stream and a second reactant stream humidifier for imparting water vapor to said second reactant stream.
- 50 12. The electric power generation system of claim 11 wherein a water separator is interposed between said first reactant stream outlet and said suction inlet whereby at least a portion of the water contained in said first reactant stream is removed.
- 55 13. A method for recirculating a first reactant stream in

an electric power generation system comprising a fuel cell stack comprising a first reactant stream inlet, a first reactant stream outlet, an second reactant stream inlet, and at least one fuel cell for promoting the electrocatalytic reaction of the first reactant stream introduced at the first reactant stream inlet with a second reactant stream introduced at the second reactant stream inlet to produce electricity, reaction product, and heat, the system further comprising a pressurized first reactant supply having a pressure control valve for regulating the pressure of the first reactant supply, and a pressurized second reactant supply, the method comprising the steps of:

- (a) interposing a vacuum ejector between the first reactant supply and the first reactant stream inlet, said ejector comprising a motive inlet, a suction inlet, and a discharge outlet;
- (b) fluidly connecting said motive inlet to said first reactant supply;
- (c) fluidly connecting said suction inlet to said first reactant stream outlet;
- (d) fluidly connecting said discharge outlet to said first reactant stream inlet;
- (e) interposing a first pressure transducer between said discharge outlet and said suction inlet, said first pressure transducer capable of detecting the pressure of said first reactant stream and transmitting a corresponding signal to said pressure control valve;
- (f) transmitting a signal to said pressure control valve to increase the pressure of said first reactant supply when the detected pressure of said first reactant stream falls below a predetermined value;
- (g) transmitting a signal to said pressure control valve to decrease the pressure of said first reactant supply when the detected pressure of said first reactant stream exceeds a predetermined value;
- (h) interposing a second pressure transducer between said second reactant supply and said second reactant stream inlet, said second pressure transducer capable of detecting the pressure of said second reactant stream and transmitting a corresponding signal to said pressure control valve;
- (i) transmitting a signal to said pressure control valve to increase the pressure of said first reactant supply when the detected pressure of said second reactant stream increases; and
- (j) transmitting a signal to said pressure control valve to decrease the pressure of said first reactant supply when the detected pressure of said second reactant stream decreases.

14. The method of claim 13 wherein said first reactant

stream comprises hydrogen and said second reactant stream comprises oxygen.

5 Patentansprüche

1. System zur Erzeugung elektrischer Energie, umfassend:

- (a) einen Brennstoffzellenstapel, welcher einen ersten Reaktandenstromeinlaß, einen ersten Reaktandenstromauslaß, einen zweiten Reaktandenstromeinlaß und mindestens eine Brennstoffzelle zur Förderung einer elektrokatytischen Reaktion eines über den ersten Reaktandenstromeinlaß eingeführten ersten Reaktandenstroms mit einem über den zweiten Reaktandenstromeinlaß eingeführten zweiten Reaktandenstroms umfaßt, um Elektrizität, Reaktionsprodukt und Wärme zu erzeugen;
- (b) eine erste Quelle für einen unter Druck stehenden Reaktanden, mit einem Druckregelventil zum Regulieren des Drucks der ersten Reaktandenquelle;
- (c) einen zwischen der ersten Reaktandenquelle und dem ersten Reaktandenstromeinlaß angeordneten Vakuum-Ejektor, wobei der Ejektor einen Treibfluideinlaß, eine Ansaugöffnung und eine Ausstoßöffnung umfaßt, wobei der Treibfluideinlaß in fluidischer Verbindung mit der ersten Reaktandenquelle steht, die Ansaugöffnung in fluidischer Verbindung mit dem ersten Reaktandenstromauslaß steht und die Ausstoßöffnung in fluidischer Verbindung mit dem ersten Reaktandenstromeinlaß steht;
- (d) einen ersten Druckwandler, der in dem ersten Reaktandenstrom zwischen der Ausstoßöffnung und der Ansaugöffnung angeordnet ist, wobei der erste Druckwandler den Druck des ersten Reaktandenstroms detektiert und ein entsprechendes Signal an das Druckregelventil übermittelt;
- (e) eine zweite Quelle für einen unter Druck stehenden Reaktanden in fluidischer Verbindung mit dem zweiten Reaktandenstromeinlaß; und
- (f) einen zweiten Druckwandler, der zwischen der zweiten Reaktandenquelle und dem zweiten Reaktandenstromeinlaß angeordnet ist, wobei der zweite Druckwandler dazu befähigt ist, den Druck des zweiten Reaktandenstroms zu detektieren und ein entsprechendes Signal an das Druckregelventil zu übermitteln;

- wodurch der erste Druckwandler dem Druckregelventil ein Signal zum Erhöhen des Drucks der ersten Reaktandenquelle übermittelt, wenn der detektierte Druck des ersten Reaktandenstroms unter einen vorgegebenen Wert fällt, und der erste Druckwandler dem Druckregelventil ein Signal zum Senken des Drucks der ersten Reaktandenquelle übermittelt, wenn der detektierte Druck des ersten Reaktandenstroms einen vorgegebenen Wert überschreitet, und wodurch der zweite Druckwandler dem Druckregelventil ein Signal zum Erhöhen des Drucks der ersten Reaktandenquelle übermittelt, wenn der detektierte Druck des zweiten Reaktandenstroms steigt, und der zweite Druckwandler dem Druckregelventil ein Signal zum Senken des Drucks der ersten Reaktandenquelle übermittelt, wenn der detektierte Druck des zweiten Reaktandenstroms sinkt.
2. System zur Erzeugung elektrischer Energie nach Anspruch 1, wobei der Brennstoffzellenstapel ferner einen zweiten Reaktandenstromauslaß umfaßt.
3. System zur Erzeugung elektrischer Energie nach Anspruch 1, wobei der erste Druckwandler in dem ersten Reaktandenstrom zwischen der Ausstoßöffnung und dem ersten Reaktandenstromeinlaß angeordnet ist.
4. System zur Erzeugung elektrischer Energie nach Anspruch 1, wobei der erste Druckwandler dem Druckregelventil ein elektronisches Signal übermittelt, welches zu dem detektierten Druck des ersten Reaktandenstroms korrespondiert.
5. System zur Erzeugung elektrischer Energie nach Anspruch 1, wobei der erste Druckwandler dem Druckregelventil ein hydraulisches Signal übermittelt, welches zu dem detektierten Druck des ersten Reaktandenstroms korrespondiert.
6. System zur Erzeugung elektrischer Energie nach Anspruch 1, wobei der erste Druckwandler dem Druckregelventil ein pneumatisches Signal übermittelt, welches zu dem detektierten Druck des ersten Reaktandenstroms korrespondiert.
7. System zur Erzeugung elektrischer Energie nach Anspruch 1, wobei der erste Reaktand ein Brennstoff ist und der zweite Reaktand ein Oxidationsmittel ist.
8. System zur Erzeugung elektrischer Energie nach Anspruch 7, wobei die erste Quelle für einen unter Druck stehenden Reaktanden im wesentlichen reinen Wasserstoff umfaßt.
9. System zur Erzeugung elektrischer Energie nach Anspruch 8, wobei die zweite Quelle für einen unter Druck stehenden Reaktanden Sauerstoff umfaßt und das Reaktionsprodukt Wasser ist.
- 5 10. System zur Erzeugung elektrischer Energie nach Anspruch 9, wobei die zweite Reaktandenquelle sauerstoffhaltige Luft ist.
- 10 11. System zur Erzeugung elektrischer Energie nach Anspruch 1, wobei die mindestens eine Brennstoffzelle eine Ionenaustrauschermembran umfaßt und wobei das System ferner einen ersten Reaktandenstrombefeuhter zum Einbringen von Wasserdampf in den ersten Reaktandenstrom und einen zweiten Reaktandenstrombefeuhter zum Einbringen von Wasserdampf in den zweiten Reaktandenstrom umfaßt.
- 15 12. System zur Erzeugung elektrischer Energie nach Anspruch 11, wobei eine Wasserabscheidevorrichtung zwischen dem ersten Reaktandenstromauslaß und der Ansaugöffnung angeordnet ist, wodurch mindestens ein Teil des in dem ersten Reaktandenstrom enthaltenen Wassers entfernt wird.
- 20 13. Verfahren zum Rezirkulieren eines ersten Reaktandenstroms in einem System zur Erzeugung von elektrischer Energie, welches einen Brennstoffzellenstapel mit einem ersten Reaktandenstromeinlaß, einem ersten Reaktandenstromauslaß, einem zweiten Reaktandenstromeinlaß und mindestens einer Brennstoffzelle zur Förderung der elektrokatalytischen Reaktion des über den ersten Reaktandenstromeinlaß eingeführten ersten Reaktandenstroms mit einem über den zweiten Reaktandenstromeinlaß eingeführten zweiten Reaktandenstroms umfaßt, um Elektrizität, Reaktionsprodukt und Wärme zu erzeugen, wobei das System ferner eine erste Quelle für einen unter Druck stehenden Reaktanden mit einem Druckregelventil zum Regulieren des Drucks der ersten Reaktandenquelle und eine zweite Quelle für einen unter Druck stehenden Reaktanden umfaßt, wobei das Verfahren die Schritte umfaßt:
- 25 (a) Anordnen eines Vakuum-Ejektors zwischen der ersten Reaktandenquelle und dem ersten Reaktandenstromeinlaß, wobei der Ejektor einen Treibfluideinlaß, eine Ansaugöffnung und eine Ausstoßöffnung umfaßt;
- 30 (b) Herstellen einer Fluidverbindung zwischen dem Treibfluideinlaß und der ersten Reaktandenquelle;
- 35 (c) Herstellen einer Fluidverbindung zwischen der Ansaugöffnung und dem ersten Reaktandenstromauslaß;
- 40
- 45
- 50
- 55

(d) Herstellen einer Fluidverbindung zwischen der Ausstoßöffnung und dem ersten Reaktandenstromeinlaß;	5	tique du courant du premier réactant introduit au niveau de ladite entrée du courant du premier réactant avec un courant d'un second réactant introduit au niveau de ladite entrée du courant du second réactant pour produire de l'électricité, un produit de réaction et de la chaleur ;
(e) Anordnen eines ersten Druckwandlers zwischen der Ausstoßöffnung und der Ansaugöffnung, wobei der erste Druckwandler dazu befähigt ist, den Druck des ersten Reaktandenstroms zu detektieren und ein entsprechendes Signal an das Druckregelventil zu übermitteln;	10	(b) une alimentation sous pression du premier réactant possédant une soupape de commande de pression pour régler la pression de ladite alimentation du premier réactant ;
(f) Übermitteln eines Signals an das Druckregelventil, um den Druck der ersten Reaktandenquelle zu erhöhen, wenn der detektierte Druck des ersten Reaktandenstroms unter einen vorgegebenen Wert fällt;	15	(c) un éjecteur à dépression intercalé entre ladite alimentation du premier réactant et ladite entrée du courant du premier réactant, ledit éjecteur comprenant une entrée motrice, une entrée d'aspiration et une sortie de refoulement, ladite entrée motrice étant raccordée du point de vue fluidique à ladite alimentation du premier réactant, ladite entrée d'aspiration étant raccordée de façon fluidique à ladite sortie du courant du premier réactant, et ladite sortie de décharge étant raccordée de façon fluidique à ladite entrée du courant du premier réactant ;
(g) Übermitteln eines Signals an das Druckregelventil, um den Druck der ersten Reaktandenquelle zu senken, wenn der detektierte Druck des ersten Reaktandenstroms einen vorgegebenen Wert überschreitet;	20	(d) un premier transducteur de pression intercalé dans ledit courant du premier réactant entre ladite sortie de décharge et ladite entrée d'aspiration, ledit premier transducteur de pression détectant la présence dudit courant du premier réactant et transmettant un signal correspondant à ladite soupape de commande de pression ;
(h) Anordnen eines zweiten Druckwandlers zwischen der zweiten Reaktandenquelle und dem zweiten Reaktandenstromeinlaß, wobei der zweite Druckwandler dazu befähigt ist, den Druck des zweiten Reaktandenstroms zu detektieren und ein entsprechendes Signal an das Druckregelventil zu übermitteln;	25	(e) une alimentation sous pression du second réactant raccordée de façon fluidique à ladite entrée du courant du second réactant ; et
(i) Übermitteln eines Signals an das Druckregelventil, um den Druck der ersten Reaktandenquelle zu erhöhen, wenn der detektierte Druck des zweiten Reaktandenstroms steigt;	30	(f) un second transducteur de pression intercalé entre ladite alimentation du second réactant et ladite entrée du courant du second réactant, ledit second transducteur de pression étant apte à déetecter la pression dudit courant du second réactant et à transmettre un signal correspondant à ladite soupape de commande de pression ;
(j) Übermitteln eines Signals an das Druckregelventil, um den Druck der ersten Reaktandenquelle zu senken, wenn der detektierte Druck des zweiten Reaktandenstroms sinkt.	35	dans lequel ledit premier transducteur de pression transmet un signal à ladite soupape de commande de pression pour augmenter la pression de ladite alimentation du premier réactant lorsque la pression détectée dudit courant du premier réactant tombe au-dessous d'une valeur prédéterminée, et ledit premier transducteur de pression transmet un signal à ladite soupape de commande de pression pour réduire la pression de ladite alimentation du
14. Verfahren nach Anspruch 13, wobei der erste Reaktandenstrom Wasserstoff umfaßt und der zweite Reaktandenstrom Sauerstoff umfaßt.	40	
Revendications	45	
1. Système de production d'énergie électrique, comprenant :	50	
(a) un empilage de piles à combustible comprenant une entrée pour le courant d'un premier réactant, une sortie pour le courant du premier réactant, une entrée pour le courant d'un second réactant, et au moins une pile à combustible pour favoriser une réaction électrocataly-	55	

- premier réactant lorsque la pression détectée de ladite vapeur du premier réactant dépasse une valeur prédéterminée, et dans lequel ledit second transducteur de pression transmet un signal à ladite soupape de commande de pression pour augmenter la pression de ladite alimentation du premier réactant lorsque la pression détectée dudit courant du second réactant augmente, et ledit second transducteur de pression transmet un signal à ladite soupape de commande de pression pour réduire la pression de ladite alimentation du premier réactant lorsque la pression détectée dans ledit courant du second courant diminue.
2. Système de production d'énergie électrique selon la revendication 1, dans lequel ledit empilage de piles à combustible comprend en outre une sortie pour la vapeur du second réactant.
3. Système de production d'énergie électrique selon la revendication 1, dans lequel ledit premier transducteur de pression est intercalé dans ledit courant du premier réactant entre ladite sortie de décharge et ladite entrée du courant du premier réactant.
4. Système de production d'énergie électrique selon la revendication 1, dans lequel ledit premier transducteur de pression transmet un signal électronique à ladite soupape de commande de pression, qui correspond à la pression détectée de ladite vapeur du premier réactant.
5. Système de production d'énergie électrique selon la revendication 1, dans lequel ledit premier transducteur de pression transmet à ladite soupape de commande de pression un signal hydraulique qui correspond à la pression détectée dudit courant du premier réactant.
6. Système de production d'énergie électrique selon la revendication 1, dans lequel ledit premier transducteur de pression transmet à ladite soupape de commande de pression un signal pneumatique qui correspond à la pression détectée dudit premier courant de réactant.
7. Système de production d'énergie électrique selon la revendication 1, dans lequel ledit premier réactant est un combustible et ledit second réactant est un agent oxydant.
8. Système de production d'énergie électrique selon la revendication 7, dans lequel ladite alimentation du premier réactant sous pression comprend essentiellement de l'hydrogène pur.
9. Système de production d'énergie électrique selon la revendication 8, dans lequel ladite alimentation sous pression du second réactant comprend de l'oxygène et ledit premier réactant est de l'eau.
10. Système de production d'énergie électrique selon la revendication 9, dans lequel ladite alimentation du second réactant est de l'air contenant de l'oxygène.
11. Système de production d'énergie électrique selon la revendication 1, dans lequel ladite au moins une pile à combustible comprend une membrane échangeuse d'ions et le système comporte en outre un humidificateur du courant du premier réactant servant à appliquer une vapeur d'eau audit courant du premier réactant, et un humidificateur pour le courant du second réactant, servant à appliquer de la vapeur d'eau audit courant du second réactant.
12. Système de production d'énergie électrique selon la revendication 11, dans lequel un séparateur d'eau est intercalé entre ladite sortie du courant du premier réactant et ladite entrée d'aspiration, ce qui a pour effet qu'au moins une partie de l'eau contenue dans ledit courant du premier réactant est éliminée.
13. Procédé pour faire recirculer un courant du premier réactant dans un système de production d'énergie électrique comprenant un empilage de piles à combustible comportant une entrée pour le courant du premier réactant, une sortie pour le courant du premier réactant, une entrée pour le courant du second réactant et au moins une pile à combustible pour favoriser la réaction électrocatalytique du courant du premier réactant introduit à l'entrée du courant du premier réactant, avec un courant du second réactant introduit au niveau de l'entrée du courant du second réactant pour produire de l'électricité, un produit de réaction et de la chaleur, le système comprenant en outre une alimentation sous pression du premier réactant possédant une soupape de commande de pression pour régler la pression de l'alimentation du premier réactant, et une alimentation sous pression du second réactant, le procédé incluant les étapes consistant à :
- (a) intercaler un éjecteur à dépression entre l'alimentation du premier réactant et l'entrée du courant du premier réactant, ledit éjecteur comprenant une entrée motrice, une entrée d'aspiration et une sortie de décharge ;
 - (b) raccorder fluidiquement ladite entrée motrice à ladite alimentation du premier réactant ;
 - (c) raccorder fluidiquement ladite entrée d'aspiration à ladite sortie du courant du premier réactant ;

(d) raccorder fluidiquement ladite sortie de décharge à ladite entrée du courant du premier réactant ;

(e) intercaler un premier transducteur de pression entre ladite sortie de refoulement et ladite entrée d'aspiration, ledit premier transducteur de pression étant à même de détecter la pression dudit premier courant de réactant et de transmettre un signal correspondant à ladite 5 soupape de commande de pression ;

(f) transmettre un signal à ladite soupape de commande de pression pour augmenter la 15 pression de ladite alimentation du premier réactant lorsque la pression détectée du courant du premier réactant tombe au-dessous d'une valeur prédéterminée ;

(g) transmettre un signal à ladite soupape de 20 commande de pression pour réduire la pression de l'alimentation du premier réactant lorsque la pression détectée dudit courant du premier réactant dépasse une valeur prédéterminée ; 25

(h) intercaler un second transducteur de pression entre ladite alimentation du second réactant et ladite entrée du courant du second réactant, ledit second transducteur de pression 30 étant apte à détecter la pression dudit réactant du second courant et à transmettre un signal correspondant à ladite soupape de commande de pression,

35

(i) transmettre un signal à ladite soupape de commande de pression pour accroître la pression de ladite alimentation du premier réactant lorsque la pression détectée dudit courant du second réactant augmente ; et 40

(j) transmettre un signal à ladite soupape de commande de pression pour réduire la pression de ladite alimentation du premier réactant lorsque la pression détectée de ladite vapeur du second réactant diminue. 45

14. Procédé selon la revendication 13, selon lequel ledit courant du premier réactant comprend de l'hydrogène et ledit courant du second réactant comprend de l'oxygène. 50

55

